In-Vehicle Application of Flexible FUREKI

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Sumitomo Electric Industries Ltd. started the development of the flexible wiring board “FUREKI” in the 1960s. Being light, thin, and highly flexible, FUREKI was well received by the market, and has been in high demand for the internal wiring of handheld units since the 1980s. Combining new materials and new technologies (such as connection technologies), Sumitomo Electric has added new products to the FUREKI series. This paper introduces our efforts for the application of FUREKI to automobiles.

Keywords: FUREKI, flexible, resistance to heat, long size, internal wiring

1. Introduction

There is a growing demand for flexible printed circuits (FPCs) as internal wiring materials for use in mobile devices, which are increasingly required to be small, light, and low-profile. Meanwhile, their applications are also increasing in automobiles for their lightness in view of the environment and as a wiring material contributing to improved mountability in equipment. This paper describes the history of the FPC business of Sumitomo Electric Industries, Ltd., FPC technology in general, and Sumitomo Electric’s approaches to use FPCs for automotive applications.

2. History of Sumitomo Electric’s FPC Business and Technical Trends

2-1 History of Sumitomo Electric’s FPC business[1],[2]

Developed in the United States around 1960, FPCs are relatively new wiring materials. Compared with general-purpose engineering plastics, polyimide (PI) is high in resistance to heat and chemicals. An FPC is structured of copper foils covered with thin PI films. Therefore, the resultant film-like printed circuit board is highly flexible and with high flexural strength. In the 1970s, FPCs were adopted as internal wiring components in card calculators and compact cameras. In the 2010s, they began to be used without exception in mobile devices such as smartphones and tablet computers. Sumitomo Electric began to work on the development of the FPC board “FUREKI” in 1965 at its Osaka Works. In 1969, Sumitomo Electric started its FPC business setting up the Development Section for Component Materials. In 1989, Sumiden Circuits, Inc. was founded as an FPC production subsidiary. In 1990, to meet orders for FPCs for consumer equipment applications such as video cassette recorders (VCRs), the company began integrated production of FPCs at the Shiga Works (present Ishibe Works of Sumitomo Electric Printed Circuits, Inc.). Moreover, in line with its customers’ moves towards shifting their production bases to overseas locations, Sumitomo Electric started running the final part of the FPC production process in Shenzhen in China in 1994. In 1996 in the Philippines, First Sumiden Circuits, Inc. was founded, which commenced integrated production of single-sided FPCs the following year to supply the products to Southeast Asia. In 2000 in Japan, Sumitomo Electric opened the Minakuchi Works. To enhance the strength and restructure the organization of Japanese sites, business center functions were centralized at the Minakuchi Works, operating as Sumitomo Electric Printed Circuits, Inc. FPC manufacturing functions in Japan moved to the new company. Since 2000, along with the widespread use of mobile phones, demand has grown for double-sided boards and multilayered boards. To meet this demand, additional production lines were established at the Minakuchi Works. Sumitomo Electric also expanded its overseas FPC production capacity and enhanced the parts mounting lines, commencing operation in 1999.

In 2009, Sumitomo Electric purchased the FPC base material business of Tokai Rubber Industries, Ltd. (present Sumitomo Riko Co., Ltd.) and opened the Fuji-Susono Plant. In 2007, Sumitomo Electric’s plant in Vietnam began to operate the final part of the FPC production process. Furthermore, in 2012, a new company, SEI Electronic Components (Vietnam), Ltd., was founded. Our FPC production in Vietnam moved to the new company. Figure 1 shows Sumitomo Electric’s present FPC production sites.

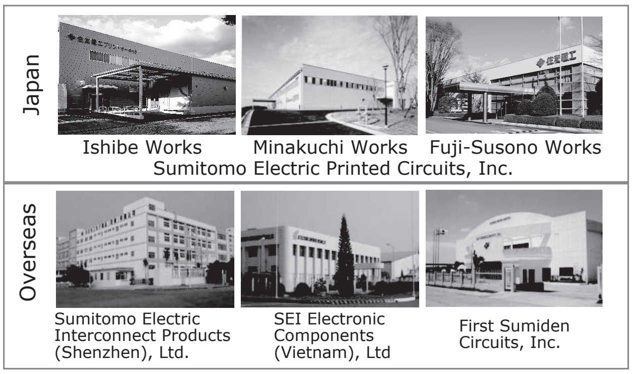


Fig. 1. FPC production sites

2-2 FPC technology

The basic structure of an FPC is that a copper foil layer formed into a circuit and insulating PI layers are laminated with a thermosetting adhesive. This structure is intended to protect the FPC circuit from external stress. For mobile device applications, 2-layer base materials made by direct bonding between a copper foil and PI without the use of an adhesive are also employed to meet demand for finer circuits and thinner FPCs. Since FPCs are thin and soft, a reinforcement is bonded to the side opposite to the parts mounting side to ensure flatness for parts mounting and to protect the parts mounted block. FPCs with two or more copper foil layers are provided with continuity between the copper layers by means of plated through hole (PTH).*[1] For FPCs on which components are mounted, non-through hole blind via holes (BVHs)*[2] are used and parts are mounted over conductive holes to achieve high-density mounting.

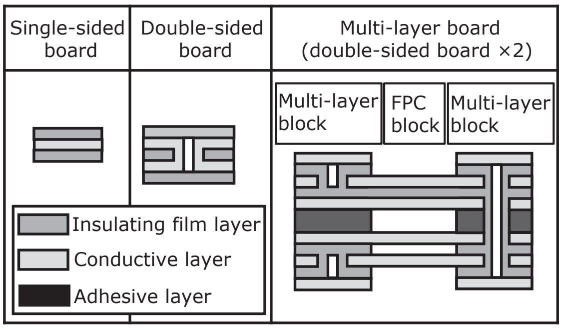


Fig. 2. FPC cross section

FPC materials of copper foils and insulating films are tuned to have similar thermal expansion coefficients to ensure reliability against ambient temperature change. If high-frequency characteristics are critical in a design, either a liquid crystal polymer (LCP) or fluororesin is selected for a lower dielectric constant than PI. To meet the applicable requirements and specifications, relatively inexpensive electrolytic copper foils, electrolytic copper foils with improved resistance to folding, or rolled copper foils with superb resistance to folding are selected.

The FPCs described above are intended for consumer products. Compared with them, FPCs for in-vehicle applications should meet the challenge of increased size due to harsher operating environments. This calls for the use of additional measures. Next, this report describes in-vehicle application examples of Sumitomo Electric's FPCs, followed by its in-vehicle FPC technology development.

3. Rollout of FUREKI for In-Vehicle Applications

3-1 Pressure sensor FPCs

In-vehicle pressure sensors contribute to control by converting detected pressures to electrical signals and activating actuators according to the electrical signals. Automotive controllers, such as those in power, drive, air-conditioning, and exhaust gas systems, have pressure sensors incorporated. In-vehicle components are on an increasing trend to serve user needs in terms of safety, sense of security, comfort, and convenience. Consequently, we have recognized the challenge for these components for in-vehicle applications to meet the need for reduced weight and size. Sumitomo Electric is striving to resolve this challenge by making the optimal use of FPCs.

Figure 3 shows an example pressure sensor device and its internal structure. Conventional sensor devices required: (1) circuits incorporating integrated circuits (ICs), (2) wiring to send out electrical signals from ICs, and a connector that connects between (1) circuits and (2) wiring. The need for the connector can be eliminated by forming both (1) circuits incorporating ICs and (2) wiring on an FPC, as illustrated in Fig. 4. The disuse of the connector implies the resultant possibility of a reduced size of the pressure sensor, because the wiring section can be bent into a "U" shape for compact packaging. In this example, the features of FPCs comprising circuits and wiring and being flexible are combined to achieve size reduction and space saving. Additionally, this design is advantageous in that it becomes suitable for pressure sensors used at various locations simply by altering its external package.

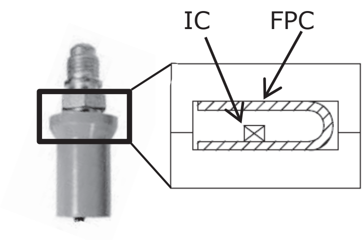


Fig. 3. In-Vehicle pressure sensor and its internal structure

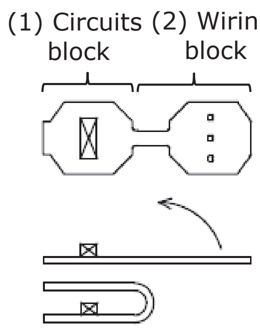


Fig. 4. Top view and fitted form of FPC

3-2 FPCs for angle sensors

Along with vehicle electrification, means of transmitting maneuvering actions has shifted from mechanical to electrical. The term by-wire is used to express this electrical transmission. By-wire devices have been increasingly introduced into many maneuvering system components such as accelerator, brakes, gearshift, and steering.

To make devices by-wire, one required function is sensing used to detect the amount of maneuver. Shift-by-wire uses FPCs in angle sensors. FPCs contribute to making the sensors low-profile.

Figure 5 shows an FPC used in an angle sensor. It comprises (1) circuits incorporating ICs to detect the state of the gear based on the angle of rotation and outputting electrical signals and (2) wiring that sends out the electrical signals. Similarly to the aforementioned pressure sensor FPC, it is possible to eliminate the use of a connector between (1) circuits and (2) wiring by forming these features into one FPC. Moreover, using a metal reinforcement, (1) circuits are made highly rigid despite their total thickness being small at 0.5 mm or less. This contributes to stable sensor accuracy and improved durability.

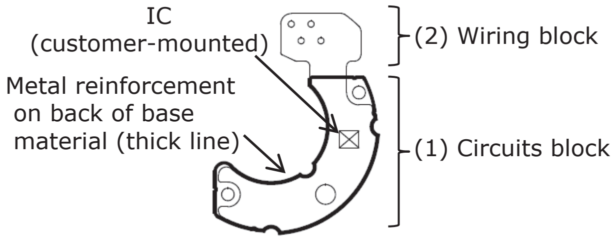


Fig. 5. Angle sensor FPC

Angle sensors of shift-by-wire systems are located in the engine compartment. Therefore, angle sensor FPCs are required to be highly resistant to heat. FPCs incorporating a highly heat-resistant material developed by Sumitomo Electric, described below, are selected for the internal wiring of sensors operating in high-temperature environments.

3-3 Inverter wiring FPCs

Automobiles propelled by an electric motor are attracting interest as environmentally friendly vehicles. Typical constituent elements of these automobiles are a battery, motor, and inverter. An inverter contains many wires connecting control PCBs, as illustrated in Fig. 6. These connecting wires must be shielded because they are surrounded by plenty of noise.

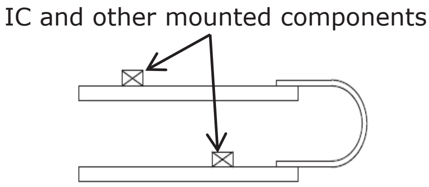


Fig. 6. Wires connecting between PCBs inside inverter

Figure 7 presents a cross section of an inverter FPC. This design, although simple, achieves noise shielding by incorporating a double-sided board and using the inner copper circuits of the mounted FPC as transmitting wiring, with the outer copper circuits serving as a shield.

Applications of this FPC design are not limited to inverters. It is suitable for wiring where shielding must be provided against noise from outer directions of a folded FPC.

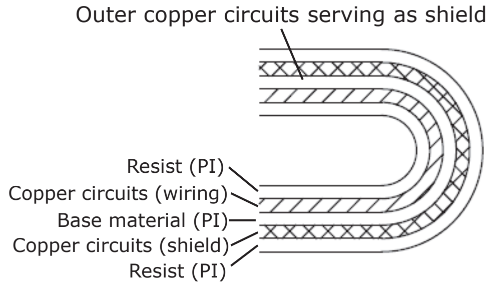


Fig. 7. Cross section of inverter FPC

4. Technology Development for In-Vehicle FUREKI

4-1 Heat-resistant FPCs

Along with advances and improvements in car electronics sophistication and performance, many components such as sensors, electronic control units (ECUs),*3 and actuators have become mounted in the engine compartment and in proximity to the motor, and, therefore, subject to high temperatures. As a result, there is growing demand for FPCs that are thin, light-weight, and suitable for high-density wiring.

In this respect, conventional FPCs had drawbacks. For example, at an ambient operating temperature of 150°C, the adhesive, the constituent material with the lowest resistance to heat, decreased in bond strength due to aging, resulting in the PI film peeling off the conductor. To address this problem, Sumitomo Electric has developed a highly heat-resistant and reliable PI adhesive, utilizing its years of experience in heat-resistant polymer synthesis technology. To achieve this, we synthesized an innovative copolymerized*4 polymer at an optimized ratio of PI resin to thermoplastic resin and used a cross-linking agent to cross-link between the copolymerized resins.[3]

Using the newly developed adhesive and a conventional adhesive when affixing a surface-treated base material and a cover lay to circuits, we fabricated prototype FPCs (newly developed and conventional FPCs). These were compared with each other and evaluated as to their resistance to heat and reliability at 150°C. After removing the samples from a thermostatic chamber and from a thermo-hygrostat, the bond strength of these adhesives was evaluated using a tensile testing machine at room temperature in accordance with the 180° peel strength measurement method (JIS K 6854). The results are shown in Fig. 8. The FPCs were heated in a 150°C thermostatic chamber for 3,000 h. Subsequently, their bond strength was measured. Compared with our conventional FPC, the newly developed FPC exhibited both high resistance to heat and reliability, meeting the JPCA standard*5 (≥ 3.4 N/cm) for bond strength even after heating at 150°C for 3,000 h. Figure 9

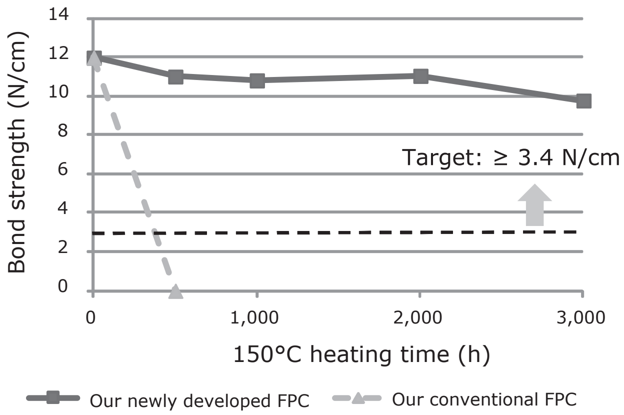


Fig. 8. 150°C resistance to heat and reliability of our newly developed and conventional FPCs

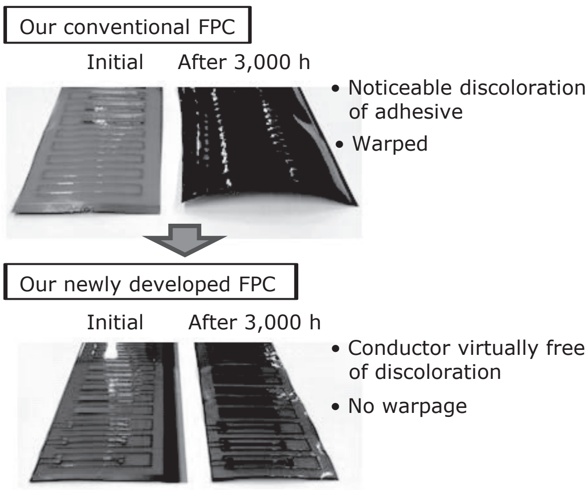


Fig. 9. Exteriors of our newly developed and conventional FPCs

shows the exteriors of the samples before and after 3,000 h heating. The newly developed FPC was more resistant to post-heating discoloration than the conventional one and free of warpage.

Regarding the aging of the newly developed FPC placed under an 85°C and 85% RH damp heat load, the bond strength did not decrease even after 3,000 h.

Table 1 summarizes the evaluation results for the newly developed FPC. The FPC fabricated using the newly developed adhesive was evaluated as to its characteristics after mounting soldered components. The results showed that the samples all fulfilled target values for long-term high-temperature reliability. The newly developed FPC exhibited high resistance to solder heat up to 360°C. When the adhesive was filled between circuits, no void was produced, posing no insulation problem. A PI-based adhesive has been developed, which can be used under high-temperature conditions. Using this adhesive, an FPC suitable for in-vehicle applications has been developed. Mass production of FPC products using this adhesive to bond cover lays and reinforcements commenced in 2017. They are expected to be used widely for in-vehicle applications

Table 1. Evaluation results

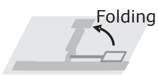
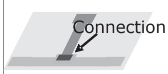
Characteristics	Target	Our newly developed FPC
(I). Long-term high-temperature reliability		
Bond strength after exposure to 150°C for 3,000 h	≥ 3.4 N/cm	9 N/cm
Bond strength after exposure to 85°C, 85% RH for 3,000 h	≥ 3.4 N/cm	10 N/cm
Bond strength after immersion in 150°C ATF oil for 3,000 h	≥ 3.4 N/cm	5 N/cm
(II). General characteristic requirements for FPCs		
Bond strength	≥ 8.0 N/cm	≥ 10 N/cm
Resistance to solder heat	≥ 280°C	360°C

along with further sophistication of car electronics and car electrification in the future.

4-2 Long FPCs

Sumitomo Electric has built production lines to meet the need for FPCs of various sizes principally for consumer products. In recent years, there has been a growing demand for long FPCs in excess of 500 mm for in-vehicle LED and battery modules. As such, it was necessary to develop FPC manufacturing methods and equipment to fulfill the demand. Table 2 compares typical manufacturing methods for long FPCs. Sumitomo Electric selects these methods appropriately to serve specific applications.

Table 2. Comparison of manufacturing methods for long branched FPCs

		(1) Single long piece	(2) Single folded piece	(3) Division into two or more pieces
Structure				
FPC length		500~1,000 mm	> 500 mm	> 500 mm
Cost*	FPC yield	**uncompetitive** (Disadvantageous to forming a branched shape)	**reasonable**	**reasonable**
	Processing	**reasonable** (No additional processing)	**expensive** (Folding process)	**expensive** (Connecting process)
	Equipment	**uncompetitive** (Long equipment)	**reasonable**	**expensive** (Connecting equipment)

*High: uncompetitive >> expensive > reasonable: Low

For example, simple FPC geometries, such as those for straight wiring, enhance yields and reduce the cost, because they can be manufactured as a single piece without any need for additional processing.

By contrast, for branched FPCs, manufacturing them as a single piece, as shown under (1) in Table 2, results in a low yield level. Folded FPCs, as shown under (2) in Table 2 or divided FPCs, as shown under (3) in Table 2, have an improved yield despite increased processes, and therefore are often advantageous in terms of cost.

Figure 10 presents an example of R&D aimed at making FPCs long through utilization of a folding technique. By developing a spiral-shaped FPC via several folds, it is elongated from a 100 × 100 mm size to a 700 × 100 mm size. Thus, conventional manufacturing methods can be used to

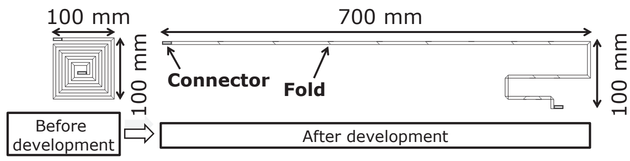
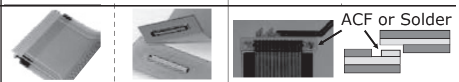


Fig. 10. Long FPC R&D example using folding technique

meet demand for long FPCs if some design changes are made.

When dividing an FPC into two or more pieces, as shown under (3) in Table 2, FPC pieces are electrically connected and integrated by the use of a connector or a direct connection method, as presented in Table 3. For FPCs designed for mobile devices, anisotropic conductive films (ACFs), which are superb for making FPCs high-density and thin, and a direct soldered connection method are used. However, specifically for in-vehicle applications, Sumitomo Electric makes propositions considering their operating locations and uses due to the issue of long-term connection reliability.

Table 3. Methods of electrical connection between FPCs

		Connection by connector		Direct Connection	
		Contact	Mounting	ACF	Solder
Schematic diagram					
Size	Lead pitch	> 0.3 mm		> 0.2 mm	
	Fitting thickness	> 1.0 mm		> 1.0 mm	

In the automotive sector, further incorporation of electronics is expected to occur in the future. Therefore, future tasks include creating innovative long products, as well as long FPCs, by combining FPCs with automotive items (wiring harnesses and electronic components) produced within the Sumitomo Electric Group.

5. Conclusion

This paper described Sumitomo Electric's approaches towards the deployment of FUREKI for automotive applications against the backdrop of the history of the Company's business and the technical trends of the market. Automotive electronics are expected to further grow along with the trends towards increasing production of electric vehicles (EVs) and autonomous driving technology. Accordingly, demand for FUREKI is also expected to become high. We intend to address challenges to meet customer expectations, solidly based on Sumitomo Electric's market track record and strength in materials and process development.

• FUREKI is a trademark or registered trademark of Sumitomo Electric Industries, Ltd.

Technical Terms

*1 Plated through hole (PTH): The hole's wall surface is plated to provide layer-to-layer electrical continuity.

*2 Blind via hole (BVH): A non-through hole the wall surface of which is plated to provide layer-to-layer electrical continuity.

*3 Electronic control unit (ECU): A component that sets the ideal amount and timing of fuel injection and the ignition timing according to the engine conditions based on information sent from sensors.

*4 Copolymerization: A high polymer compound is synthesized by bonding many units, which are small molecule compounds. The process is known as polymerization. Copolymerization is polymerization that uses two or more types of monomers.

*5 JPCA standards: Standards for electronic circuits set forth by the Japan Electronics Packaging and Circuits Association.

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